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The Holocene 2008; 18; 3
DOI: 10.1177/0959683607085780

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A HOLOCENE SPECIAL ISSUE

Abstract: Frank Oldfield's immense contribution to palaeoenvironmental science is summarized in relation to: pollen analysis, vegetation history and peat stratigraphy; palaeolimnology and ^{210}Pb dating; environmental magnetism, catchment–lake relationships and soil erosional history; multiproxy approaches; PAGES; and editing *The Holocene*. The tribute includes an introduction to the 14 other papers in this Special Issue, which were inspired in diverse ways by this remarkable scientist.

Key words: Palaeoecology, environmental magnetism, palaeolimnology, pollen analysis, peatlands, radiometric dating, soil erosion, catchment history, multiproxy approaches, PAGES, *The Holocene*.

Introduction

The papers in this special issue have been compiled in tribute to Frank Oldfield. The authors include several of his close colleagues and former students and the papers are based on presentations given at a two-day seminar in Liverpool in November 2006 arranged to celebrate Frank's 70th birthday. Frank has been one of the foremost scientists and influential leaders in the field of palaeoenvironmental science over the last 50 years. He has selflessly guided and inspired both his students and colleagues during their careers, providing intellectual and philosophical standards we all struggle to match. His scientific career has been remarkable not only for the many pioneering contributions he has made but also for the range and diversity stemming from his ability to pursue ideas and challenge received wisdom in many different areas of environmental change science. This amazing breadth is illustrated by his large number of publications on a wide range of research topics (see Appendix). Here we summarize some of his major achievements.

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Pollen analysis, vegetational history and peat stratigraphy

Frank Oldfield began his long and distinguished career in environmental history and environmental change research as a pollen analyst and vegetation historian. He gained his BA from the University of Liverpool in 1956 in which he wrote a thesis on 'The mosses and marshes of North Lancashire'. He moved for two years (1956–1958) to the then Sub-Department of Quaternary Research in the Botany School of the University of Cambridge to learn the techniques of pollen analysis and vegetational history. There Frank fell under the tutelage, intellectual stimulation and enthusiasm of Donald Walker, Harry Godwin and others.

His first pollen analytical publication (Oldfield, 1958) concerned buried peats associated with sea-level changes along the Lancashire coast. Whilst in Cambridge, and subsequently whilst on the staff at the University of Leicester (1958–1963) and the University of Lancaster (1963–1967), Frank made several further investigations on the Lateglacial and Holocene vegetation and environmental history of his native Northwest England, in particular at Haweswater in Lowland Lonsdale (Oldfield, 1960a), Urswick Tarn (Oldfield and

10.1177/0959683607085780

Figure 1 Frank Oldfield

Statham, 1963) and several raised bogs around Morecambe Bay (eg, Oldfield, 1960a, b). He pioneered the use of palaeoecological techniques in detecting the role of human activity in changing vegetation patterns in Northwest England and produced a masterly synthesis of the data in his classic paper 'Pollen analysis and man's role in the ecological history of the south-east Lake District' (Oldfield, 1963), which was revised and later brought to a wider audience in his Lister Lecture to the British Association (Oldfield, 1969).

In 1957 Madame Madeleine van Campo in Paris asked Harry Godwin if there was anyone who would be interested in working on a series of coastal peats near Biarritz in southwest France. As almost nothing was known about the vegetational history of southwest France, and as Frank was fluent in French, the invitation from van Campo was too good an opportunity to miss. Frank quickly became deeply involved in studying the series of peat deposits along the coast near Biarritz (Oldfield, 1960c, d). These deposits had a very complex stratigraphy, so Frank initially moved further inland to a site at La Moura to establish a detailed Lateglacial and Holocene pollen stratigraphy (Oldfield, 1964). It was not until he moved to Lancaster that he completed his definitive analysis and synthesis of the Pays Basque peat beds (Oldfield, 1968). He showed that several interglacial deposits were represented and, with Elizabeth Huckerby (now Vokes), he published some of the most detailed plant macrofossil records from European interglacials, with fossils of several taxa now extinct in western Europe (Huckerby and Oldfield, 1976; Oldfield and Huckerby, 1979; Huckerby *et al*., 1972).

During Frank's days at Leicester, he was asked by the then Nature Conservancy to investigate the peat stratigraphy and history of the Blelham Bog National Nature Reserve. Besides finding the now-famous Lateglacial deposits below Blelham Bog (Pennington and Bonny, 1970) he discovered that the upper peat stratigraphy and pollen stratigraphy reflected not the natural processes of succession as envisaged when the bog was declared a National Nature Reserve, but the artificial flooding of peat cuttings made in the early nineteenth century, followed by causeway building, stream diversions and variations in grazing pressure. This pioneering study (Oldfield, 1970a) was perhaps the first detailed palaeoecological study centred on the last 200–250 years and the first palaeoecological study ever of direct relevance to nature conservation. It showed the power of palaeoecology to identify 'what is natural', a topic of great concern today in conservation, nature management and restoration ecology (Willis and Birks, 2006).

Frank retained a keen interest in pollen analysis, vegetational history, land-use changes and the role of environmental change on human activity throughout his career. He conducted unique studies on the Southern High Plains in Texas and New Mexico with Jim Schoenwetter (Oldfield and Schoenwetter, 1964; Oldfield, 1975a, b; Potter *et al.,* 1975), he wrote a pioneering essay on critical aspects of scale and complexity in palaeoecology (Oldfield, 1970b), and he applied palaeoecological techniques to questions of land-use history on the highlands of Papua New Guinea (Worsley and Oldfield, 1988). All Frank's work in Papua New Guinea on pollen analysis, ^{210}Pb dating, erosion and catchment processes was initiated whilst he was the

Acting Vice-Chancellor of the University of Papua New Guinea, an example of Frank's amazing energy and enthusiasm. Later, he wrote a thoughtful and stimulating essay on research and conceptual approaches to palaeoecology and on the need for rigorous hypothesis generation and testing in palaeoecological interpretations (Oldfield, 1993). Very recently he wrote a synthesis of the role of people in the Holocene in which he integrates pollen analytical, palaeolimnological and palaeoclimatic evidence to provide a critical review of current knowledge and key research questions for the future (Oldfield, 2008).

When he moved to Lancaster in 1963, Frank was strongly influenced by the genius of the late John Mackereth at the Freshwater Biological Association's laboratory at Ferry House. Mackereth was, at that stage, exploring the idea of iodine as a possible proxy for precipitation (Pennington and Lishman, 1971). Frank immediately had the vision to try to combine detailed peat stratigraphical studies, iodine analyses and Gordon Manley's (1974) long-term climate records as a means of reconstructing and calibrating changes in precipitation. Frank thus initiated peat-stratigraphical studies at Bolton Fell Moss in Cumbria. Much of this work was conducted by his Lancaster-based research student Keith Barber (Barber, 1981) and it led subsequently to a major renaissance in peat-stratigraphical research in the United Kingdom, elsewhere in Europe and in North America (Barber, 2006). Frank's related interest in the interconnection between peat stratigraphy and sea-level change in Lowland Lonsdale was stimulated by his observations that bogs in this area were underlain by marine clays. These led to the detailed sea-level change research of Michael Tooley (Tooley, 1978) in Lancaster and thereafter to the major and extensive programmes of research into past sea-level change around the UK coast that continue today.

With his research student Paddy O'Sullivan in Lancaster and subsequently Coleraine, Frank developed further his ideas about using pollen analysis at a range of spatial scales to reconstruct and evaluate the history of specific vegetational stands of high conservation importance. The focus was on the Caledonian pine woods of Speyside in the eastern Scottish Highlands (O'Sullivan, 1973, 1974, 1975). This work at different spatial scales and Frank's thoughtful essay on questions of scale in pollen analysis (Oldfield, 1970b) were early contributions to the current research on past vegetation reconstruction using sites of different sizes and pollen source areas (Sugita, 2007a, b).

One of Frank's greatest contributions to palaeoecology was his demonstration at Blelham Bog that high resolution pollen-stratigraphical studies can provide a unique local site-scale historical record for the last 200–250 years and hence link the critical temporal gaps between modern ecology and palaeoecology. This linkage was uppermost in his mind when he moved to Coleraine and initiated a new research programme in palaeolimnology.

Palaeolimnology and ^{210}Pb dating

In 1967 Frank Oldfield moved from Lancaster to take up the chair of Geography in the newly created School of Biological and Environmental Studies at the New University of Ulster (NUU), now the University of Ulster (UU). Pivotal to his thinking at the time was the realization that the present status of natural ecosystems, even those designated as nature reserves, might owe more to the effects of human activity, especially recent human activity, than to natural processes, a view stemming especially from his Blelham Bog study noted above (Oldfield, 1970a). Whilst this appears self-evident today it was, in the 1960s, counter to the prevailing paradigm that viewed the contemporary status of bogs and lakes as the end point of natural ecosystem evolution over Holocene-length timescales. The move to Coleraine presented an opportunity to explore a more dynamic approach to questions of ecosystem change and the role of people. To this end, and together with graduate students and staff of the newly established Freshwater Laboratory at Traad Point, he used Lough Neagh to ask questions about the role of human activity in explaining the eutrophication and primary productivity history of the lake, questions stimulated by the timely occurrence of a major cyanobacterial bloom on Lough Neagh in 1967 (Wood and Smith, 1993).

The key problem at the time, however, was the lack of established methodologies needed to sample, date and analyse recent lake sediments. Under Frank's leadership the Coleraine group became one of the first to tackle these challenges using John Mackereth's pre-publication blueprint drawings to build a mini-Mackereth corer (Mackereth, 1969) in order to sample the uppermost sediments, developing the use of diatoms (Battarbee, 1973, 1978) and chironomids (Carter, 1977) as palaeo-productivity indicators, using pollen analysis to identify catchment land-use changes (Battarbee, 1973, 1978; O'Sullivan *et al*., 1973), using mineral magnetic measurements as a method of tracking catchment soil erosion (Thompson *et al*., 1975) and exploring the use of palaeomagnetism as a dating technique (Mackereth, 1971).

Frank had hoped that the documented *c.* AD 1820 westerly palaeomagnetic declination maximum in particular might be useful in helping to date recent lake sediments. Despite some early optimism this feature proved elusive in Lough Neagh and the problem of dating recent sediments had to await the arrival of ^{210}Pb dating (Krishnaswamy *et al*., 1971; Robbins, 1978). Frank's critical contribution to the development of ^{210}Pb dating came as he realized, following his attempt to date lake sediments in the New Guinea Highlands (Oldfield *et al*., 1980), that the age models currently in use were not appropriate for cores with non-monotonic concentration profiles. He proposed an alternative model, which became known as the constant rate of supply (*crs*) model. It assumed a constant flux of ^{210}Pb to the sediment, allowing ^{210}Pb concentrations in the sediment to vary with sediment accumulation rate. In close collaboration with Peter Appleby he described (Appleby and Oldfield, 1978), exemplified (Oldfield *et al*., 1978a) and tested the *crs* approach (Appleby *et al*., 1979; Oldfield and Appleby, 1984). They demonstrated that the *crs* model in the majority of cases produced the most reliable age estimates when compared with independent evidence eg, from ^{137}Cs markers (eg, Pennington *et al*., 1976) or from a comparison with a varve chronology (Appleby *et al*., 1979). His successful partnership in Liverpool with Peter Appleby led to the setting up of the Liverpool Environmental Radioactivity Laboratory, which has become the world's leading laboratory for ^{210}Pb dating.

Environmental magnetism

As noted above Frank Oldfield's early interest in palaeomagnetism was fired by John Mackereth's demonstration (Mackereth, 1971) that palaeomagnetic secular declination measurements on oriented lake sediment cores might be useful in dating Holocene lake sediments. Frank was especially excited as the method was being developed just as the limitations of ^{14}C dating were being realized for lake sediments, such as those from Lough Neagh (O'Sullivan *et al*., 1973), suffering from severe problems of older carbon contamination. While Roy Thompson followed up the use of palaeomagnetism as a dating and core-correlation method, Frank began to focus on the mineral magnetic properties of lake sediments. During the Lough Neagh work he had observed that measurements of magnetic susceptibility on replicate cores showed striking between-core similarity, an observation that led to the first use of magnetic susceptibility as a technique for core correlation (Thompson *et al*., 1975).

Frank's key insight was that the down-core fluctuations in mineral magnetic properties closely matched with palaeoenvironmental indicators of erosion in the drainage basin. This observation proved to be the starting point for a broad range of magnetic endeavours that rapidly developed into the subject area that was to become known as environmental magnetism. A large cohort of PhD students at Liverpool including John Dearing, Jan Bloemendal, Ann Worsley, John Smith, Brian Arkell, Simon Robinson, Andy Hunt, Barbara Maher, Nigel Richardson, Jenny Jones, John Sahota, Yu Lizhong, Derek France, Simon Hutchinson, Peter Crooks, Sharon Gedye and Richard Jones were sufficiently inspired to make environmental magnetism and environmental change the basis of their own research careers.

As the different sources of magnetism in lake sediments were progressively identified and understood, it was not only investigations of lake-sediment sequences that benefited from the environmental magnetism approach. Great successes were also achieved in studies of pedogenesis, especially of the Chinese loess. Here magnetic concentration fluctuations allow precise correlation with delta ^{18}O determinations in ocean cores, and hence permit an exceptionally close tie between the marine and terrestrial realms. Fluvial process work with both bedload and suspended sediments proved amenable to magnetic techniques. Frank and co-workers extended the use of magnetic measurements as a method of tracing catchment soil erosion (Oldfield *et al*., 1978b). They were also able to identify contamination of lake and peat sediments by fly ash particles from atmospheric deposition (Oldfield *et al*., 1981; Oldfield and Richardson, 1990). Heavy metal pollution sources were found to be readily established through the magnetic signatures of estuarine sediments. In deep-sea sequences mineral magnetic studies have allowed events spanning a wide range of timescales, from glacial–interglacial cycles to Heinrich episodes, to be illuminated in detail.

In retrospect one may wonder why it was that such a wealth of applications of magnetic measurements had to await the arrival of Frank onto the magnetics scene in the early 1970s. After all, the palaeomagnetists of the 1950s and 1960s were widely known as palaeomagicians. Furthermore, palaeomagnetic demonstrations of continental drift and geomagnetic reversals had been outstandingly successful and had culminated in the late 1960s in the establishment of the revolutionary earth science paradigm of plate tectonics. Perhaps the palaeomagnetic successes were simply too great, such that the focus of work was too sharply directed on the stable remanent magnetizations that could be preserved in rocks for hundreds of millions of years. Unstable, viscous magnetizations and secondary (weathering) components were an anathema to palaeomagnetism and had to be removed (demagnetized away) at all costs. Environmental magnetism, by contrast, prospers on the wide diversity of magnetic properties to be found in nature. Fortunately for the environmental magnetist the majority of natural magnetic minerals do not carry stable remanences. They are either too small (superparamagnetic), too large (multidomain), the wrong shape (equidimensional) or have the wrong mineralogy – all grist to the environmental magnetic mill.

Magnetism is at heart a laboratory-based subject. Just as palaeomagnetism (*sensu stricto*) had to await instrumental developments (such as Lord Blackett's improvements to the astatic magnetometer) before it could be applied to practical problems, so instrumental developments were germane to the widespread application of environmental magnetism. The extensive range of manufacturer's equipment available to today's generation of environmental magnetists is totally different to the limited, in-house, home-made kit used on the Lough Neagh cores. Frank played his usual, proactive role in these developments. Most notably he championed the use of frequency-dependent susceptibility and actively mentored Geoff Bartington in the commercial development of his highly successful suite of susceptibility bridges.

Environmental magnetism research remained a dominant strand of Frank's work leading to his influential book with Roy Thompson on the topic (Thompson and Oldfield, 1986) and inspiring other laboratories worldwide to adopt the approach. In short, Frank's vision that magnetism could provide a versatile methodology for the study of such a wide range of environmental contexts was a truly unique scientific contribution.

Catchment–lake relationships and soil erosional history

Frank Oldfield's interest in lake sediments, based on experiences particularly of work in Northern Ireland and Papua New Guinea led to a synthesis of ideas about environmental change, expressed in a classic paper 'Lakes and their drainage basins as units of sediment based ecological study', published in the first issue of *Progress in Physical Geography*. In this paper (Oldfield, 1977), published shortly after Frank had been appointed to the Roxby Chair of Physical Geography at Liverpool University in 1975, he offers a thought experiment to the reader: to imagine the opportunities for research if Hubbard Brook flowed into lake Windermere – essentially identifying the value of combining monitored catchment records and lake sediment-based palaeoenvironmental records. This imagined scene set the foundation for a review of the diverse techniques and methods that could be combined to reconstruct long-term environmental change. In providing a vision for a new conceptual framework, and demonstrating the multidisciplinary demands of environmental reconstruction, it was a paper that showed Frank's intellectual qualities to their full. A later paper (Oldfield, 1983) could be considered a sequel. It developed further the unique role for palaeoenvironmental records in recording long-term processes (including a widely used summary diagram of process timescales and modes of study) and introduced new views on systems theory, such as self-organization between steady states. In the past 30 years, Frank has published long-term records of catchment processes from sediment studies in Papua New Guinea, Northern Ireland, French Alps, eastern USA, southern Spain, the Adriatic, English Lake District, Easter Island, northern England, Scotland, Swiss Alps, central Italy and southwest China. These include the impact of human activities on soil erosion, the effects of fire on vegetation and the effects of climate on flooding over Holocene time spans that include early agriculture and modern farmers. Taking the studies as a whole there is an underlying message that environmental change is characterized by complex interactions between climate, human activities and ecological responses. It is a message that Frank has formalized and argued forcefully in a number of recent reviews and commentaries (Oldfield *et al*., 2000; Steffen *et al*., 2001; Oldfield and Dearing, 2003; Oldfield, 2004, 2008) and his masterly book *Environmental change: key issues and alternative approaches* (Oldfield, 2005).

Multiproxy approaches

From early work on Lough Neagh (O'Sullivan *et al*., 1973; Battarbee, 1973, 1978) in which pollen analysis, diatoms, chironomids and palaeomagnetism were combined to reconstruct recent lake and catchment history, Frank Oldfield has always encouraged a multiproxy approach in environmental history, in particular to the study of human impact on different ecological systems around the world. Given Frank's wide range of research interests and experience, and the diverse array of techniques now available within palaeoecology and environmental historical research, it was only natural that Frank should become deeply involved in detailed multiproxy studies during the last 10–15 years.

Frank was a joint leader of the Palaeoenvironmental Analysis of Italian Crater Lake and Adriatic Sediments (PALICLAS) project (Guilizzoni and Oldfield, 1996). This major international project involved high-resolution multiproxy records from comparative lacustrine and marine environments and it provided many new insights into environmental change and linkages between systems (eg, Oldfield, 1996a, b; Asioli *et al*., 1999; Ariztegui *et al.*, 2000; Guilizzoni *et al*., 2000; Oldfield *et al*., 2003a; Chondrogianni *et al*., 2004). The new multiproxy study on Lateglacial sediments at Haweswater, Lowland Lonsdale, one of Frank's first pollen-analytical sites, involving detailed stable isotope and palaeoecological analyses has highlighted new insights into leads and lags in different systems during the Lateglacial and early Holocene (Jones *et al*., 2002; Marshall *et al*., 2002). The multiproxy study at Gormire in northeast England (Oldfield *et al*., 2003b; Fisher *et al*., 2003) has provided new and exciting approaches to the study of land-use changes through the integration of novel organic geochemical techniques, sediment magnetism and geochemistry, and pollen analysis. Frank's success as a leader of major multiproxy studies was not only a result of the breadth of his knowledge but also a result of his personal qualities, especially his ability to inspire trust amongst all participants (cf. Birks and Birks, 2006).

PAGES

In 1996, Frank Oldfield joined IGBP-PAGES in Berne, Switzerland as its Executive Director. The move provided him with an excellent opportunity to promote his integrative vision for the role of palaeoenvironmental science in understanding contemporary environmental systems. It specifically allowed him to strengthen and extend the role of PAGES globally and to promote the role of palaeoscience within the wider IGBP community. As a tireless campaigner, supported by first Ray Bradley and then Tom Pedersen as PAGES chairs and by Keith Alverson in the IPO in Berne, Frank was able to establish a new palaeoecological agenda for PAGES by developing the LUCIFS, LIMPACS and HITE activities, now embodied in the new PAGES-PHAROS programme (Dearing and Battarbee, 2007). He underpinned and encouraged the Pole-Equator-Pole (PEP) programmes under the PANASH initiative of Ray Bradley and Vera Markgraf (Bradley *et al*., 1995) and he brought leading palaeoscientists together in London (1998) for the first PAGES Open Science Meeting to review the state of palaeoenvironmental science globally (Alverson *et al*., 2000). Towards the end of his tenure he was instrumental in the production of a major synthesis of PAGES science (Alverson *et al*., 2003) that presents the most powerful justification currently available for palaeoscience in understanding global change, past, present and future.

Editing *The Holocene*

Throughout his career Frank Oldfield has been a committed editor and reviewer of research papers. His major contribution has been to *The Holocene*. He was a founding member of its Editorial Board and has been an Associate Editor throughout the 17 years of the journal's existence. His editorial contribution has involved handling the referee stage of between 20 to 30 papers per year, mainly those involving human impacts, lakes and/or chronology. His decision-making has been instrumental in maintaining and improving the high standards of the journal in these areas. At least four of Frank's many qualities have been particularly evident throughout this long period of service. First and second, his broad interests and many contacts within the Holocene scientific community have enabled assessment of a wide range of topics. Third, his penetrating insights into the strengths and weakness of scientific argument ensure a fair evaluation of submitted manuscripts. And finally there is the 'wisdom of Oldfield', an indispensable quality needed in deciding whether to accept or reject a manuscript, or to recognize sufficient merit to allow a resubmission after major improvement.

Retirement

Frank Oldfield officially retired in 2001. However, the breadth and depth of Frank's research and scholarship, especially with respect to the role of human activity in understanding environmental change, continues to be illustrated in retirement by his recent book, *Environmental change: key issues and alternative approaches* (Oldfield, 2005) and by his chapter on 'The role of people in the Holocene' (Oldfield, 2008) in the forthcoming HOLIVAR book (Battarbee and Binney, 2008). He continues to act as an Associate Editor for *The Holocene*. As Emeritus Professor and Senior Research Fellow in the Department of Geography, at the University of Liverpool, Frank continues to involve himself enthusiastically in the departmental research activity more than 50 years after he graduated: notably attending and contributing to the weekly seminar series and teaching on the MSc in Climate and Environmental Change programme.

Papers in this Special Issue

The papers in this Special Issue are representative of Frank's many different research interests. The sequence of papers mainly follows the sequence adopted in this summary biography covering palaeoecology, peatlands and tephrochronology, palaeolimnology and pollution, radiometric dating, environmental magnetism, lake and landscape evolution, palaeoceanography and climate change.

In their fine-resolution pollen-stratigraphical study of the Younger Dryas–Holocene transition at Kråkenes Lake in Norway, John and Hilary Birks approach the temporal resolution of modern ecological observations of about 20 years per sample, exactly in the way that Frank Oldfield (1983) proposed should be done. John and Hilary Birks demonstrate very marked biological responses to rapid climate change 11 550 years ago and they quantify changes in richness, compositional turnover and rates of assemblage change in the first 1000 years of the Holocene. They show that there might have been a lag of about 600 years in the arrival and expansion of *Betula* since inferred July air temperatures (based on chironomids) were seemingly suitable for tree-birch growth very early in the Holocene. Their paper addresses some central issues in palaeoecology, such as lags, rates of change, temporal and spatial scales, extracting ecological signals from palaeoecological data and linking palaeoecology with contemporary ecology, issues to which Frank Oldfield introduced John Birks in the early 1960s.

Improving sediment chronology has always been a major priority for Frank Oldfield. As such, he was instrumental in driving research into the use of palaeomagnetic secular variation (Molyneux *et al*., 1972), ^{210}Pb (Appleby and Oldfield, 1978), ^{241}Am and ^{137}Cs (Oldfield *et al*., 1993), ^{32}Si (Nijampurkar *et al*., 1998) and AMS ^{14}C dating of different organic fractions (Oldfield *et al*., 1997) in order to improve chronological frameworks. In the paper by Barber *et al*. (1999) we see a further attempt to refine the dating of peat profiles using tephra. The authors review the evidence from eight ombrotrophic peat bogs from northern England and Scotland that contain the distal Glen Garry tephra, dated using AMS ^{14}C. The geochemistry of all the tephra layers is consistent with there being only one Glen Garry tephra, and the resulting dates are calibrated and wiggle-matched to give an estimated age for the Glen Garry tephra of 2176 cal. yr BP, with a 2σ range of 2210–1966 cal. BP. This age estimate will allow future work on peat profiles and other sediments containing the tephra to use the date as a pinning-point in age/depth models.

In contrast with other papers in this volume, Paddy O'Sullivan stands back from palaeoscience and questions whether palaeoscientists are capable, given the scientific method, of adequately addressing the underlying question of why people have exploited, and continue to exploit, the natural environment in a demonstrably unsustainable way. It is an issue that has exercised Frank over his career and, having been inspired by Frank as a teacher in Lancaster and as a PhD supervisor in Coleraine, Paddy O'Sullivan appropriately quotes from Frank's recent book: 'any full appraisal of the Earth system demands a deeper understanding of the role of human decisions and actions' (Oldfield, 2005: 17). Paddy advocates an anthropological approach to this issue, stressing the need to understand shifts in the relationship between society, politics and economy through time, especially with respect to the ways in which access to resources is controlled, and how resources are distributed within society. He argues that in modern stratified societies in which economic activity is intensified and progressively globalized, national policy-making becomes subservient to the global economy and overexploitation of natural resources is increased. He concludes that the goal of long-term sustainability will involve 'increased local economic self-reliance and personal and political autonomy, and enhanced ability of local communities to manage their own resources'.

Frank Oldfield's instinct in the late 1960s, reinforced by advice at that time from Dan Livingstone, that diatoms might be used as powerful indicators of recent limnological change has proved prescient. Their value has been realized none more so than in addressing the problem of surface water acidification, an environmental issue that Frank contributed to in many different ways (eg, Oldfield and Richardson, 1990; Clymo *et al.,* 1990). In their paper, Rick Battarbee and co-authors discuss the accuracy of diatom-pH transfer functions used to infer the pre-acidification pH of acidified lakes. They argue that there is an urgent need for such an assessment as palaeolimnological data are being increasingly used to define reference conditions for lake restoration. Here they use diatom-inferred pH data from diatom assemblages collected since 1990 in annually exposed sediment traps and water chemistry data over the same time period from 11 lakes to evaluate the performance of three diatom-pH transfer functions. They show that all three models tend to underpredict slightly measured pH in the less acidic sites, with the SWAP model (Birks *et al.,* 1990) being the most biased. However, when applied to core data all models were in good agreement in reconstructing pH for the AD 1850 reference period. The reference pH varied between sites from approximately 4.9 to 6.4, a variation most strongly influenced by the different base-cation status of the lakes. Comparison of the reference pH with the modern pH indicates that recovery, albeit slight, is occurring at most sites.

Whilst much of the focus of lake acidification research over the last 25 years has been on pollution problems caused by acid rain (see above and Battarbee *et al.*, this issue), John Boyle has been more concerned with natural lake acidification processes in the early Holocene (Boyle, 2007a, b) and now, in this paper, with the role of climate change. In attempting to disentangle the different causes of environmental change on decadal and longer timescales linking atmospheric, catchment and lake processes he follows closely in Frank's footsteps. Here he presents a generalized geochemical model that uses rock type, annual precipitation and temperature, aeolian dust supply and catchment to lake area ratio as predictors of lake water acidity/alkalinity. From sensitivity analyses the model suggests that direct temperature effects on surface water alkalinity are generally minor, but variations in runoff rate caused by changing precipitation or evaporation could have a substantial effect. Aeolian dust flux is also shown to be more important than climate in regulating surface water alkalinity in those areas of the world subject to above-average dust deposition.

One of Frank's seminal contributions to palaeolimnology was not only to propose an alternative age model for ^{210}Pb dating, as noted above, but also to set up, with Peter Appleby, a ^{210}Pb dating laboratory at Liverpool. Here Peter Appleby reviews the Liverpool ^{210}Pb dating programme at Liverpool over the last 30 years. In addition to providing a dating service for the palaeolimnological community throughout the world, the work has included studies of the basic processes controlling the supply of ^{210}Pb to the various natural archives. Peter describes how the assumption that ^{210}Pb fallout at any given location is constant when measured on timescales of a year or more has been tested using data on ^{210}Pb concentrations in UK rainwater spanning more than 40 years, and presents an atmospheric model that accounts for observed spatial variations in the flux over large land masses. The paper also explains how the basic assumptions of the *crs* dating model (Appleby and Oldfield, 1978) have been tested using mass balance studies of fallout radionuclides in catchment/lake systems. On the basis of the Liverpool ^{210}Pb data base Peter Appleby illustrates the wide range of lakes in terms of size and sediment accumulation rate, that have been used for ^{210}Pb dating and points out the particular difficulties of dating sediment records from desert lakes and polar regions with very low atmospheric fluxes.

In their wide-ranging paper on 'Is spring starting earlier?', Roy Thompson and his statistician colleague Malcolm Clark, use time series of the onset of leaf development, air temperature, precipitation and regional changes in CO_2 concentration. They show that for all 13 trees studied, there is an association between leafing date and air temperature. This is often a non-linear response. The modelled responses are used to estimate the impact of recent temperature changes on the date of the onset of spring. Changes in the phase of the annual CO_2 cycle are isolated statistically. Timing of the annual cycle has become steadily earlier in recent decades, supporting the idea of an earlier spring. This detailed study builds on three of Frank Oldfield's long-term research interests, human impact, pollen and historical archives, and takes advantage of Ed Deevey's (1969) idea of 'coaxing history to conduct experiments', an idea that Frank has so elegantly developed in many of his projects.

Rob Hatfield and Barbara Maher build on Frank's studies on the use of magnetic measurements to infer sediment-source linkages (eg, Thompson *et al*., 1975; Oldfield, 1977; Oldfield *et al*., 1979), making comparisons between the properties of fluvial and limnic sediments in the Lake District lake-catchment system of Bassenthwaite. Bassenthwaite is a vulnerable Site of Special Scientific Interest, with water quality problems linked to the accelerated delivery of fine sediment. The authors cleverly avoid the confounding effects of fine bacterial magnetosomes in the lake sediments by restricting comparisons to the larger particle-size fractions. Magnetic comparisons between the potential detrital sources and the lake surface sediments indicate that Newlands Beck, providing only ~10% of the lake's hydraulic load, is the main contributor of sediment to the deep basin of the lake.

Frank Oldfield's quest for using the past to inform about the functioning of modern environmental systems (eg,Oldfield, 1983) is mirrored in John Dearing's attempt to apply resilience theory to lake sediment based histories of environmental processes in China. The paper explores the use of resilience theory to provide an improved theoretical framework for the analysis of socio-ecological interactions over decadal–millennial timescales, identifying landscape system behaviour through analysis of proxy records for land use, erosion and monsoon intensity over the past 3000 years in the Erhai lake-catchment system, Yunnan, SW China. Comparison of detrended time-series data suggests that over 3000 years erosion and land use should be considered 'slow' processes relative to the 'faster' monsoon intensity and flooding. Mapping the adaptive cycle on to the millennial record of land use and erosion suggests that the modern landscape may be approaching a 'conservation' phase characterized by minimum resilience. Such 'historical profiling' of modern landscapes was at the heart of Frank's vision to construct international science agenda, like the original PAGES Focus 3 programme (Oldfield *et al*., 2000) that could provide an improved basis for hypothesis testing, defining pre-impact states, and developing and testing simulation models – all with the aim of formulating improved management strategies.

Reconstructing environmental change in the English Lake District was an early fascination for Frank Oldfield (Oldfield, 1963), but a full and comprehensive chronological framework for the entire Holocene has been frustrated by the lack of optimum and independent dating techniques. Progress in this endeavour comes from the paper by Zhixiong Shen *et al*., where we see the first successful attempt to date UK Holocene lake sediments using another technique: optically stimulated luminescence (OSL) on fine silt quartz grains. The results from Crummock Water in the English Lake District show that OSL dates compare well with ^{14}C dates made on terrestrial plant macrofossils, indicating that OSL dating can not only be used to date lake sediments in the UK but also that macrofossil-based ^{14}C dating of lake sediments can be used with a reasonable degree of confidence to avoid 'old carbon' errors. The major changes in the dated magnetic record from Crummock Water, interpreted in terms of the Lateglacial/Holocene climatic shift at around 11 400 cal. yr BP, the regional onset of human activity from ~ 4000 cal. yr BP, and particularly the intensification of human activity at around AD 900 not only complement but also confirm some of the earliest reconstructed changes in the region.

Well before it was fashionable, Frank Oldfield was a strong advocate of using comparisons between lake and marine sediment records as a means of linking scales of enquiry especially with respect to identifying the different effects of local and regional controls on environmental change. An opportunity to exemplify the approach arose through the EU project PALICLAS (Guilizzoni and Oldfield, 1996) that involved a comparison between sediments from Italian crater lakes and sediment from the Adriatic Sea. The next two papers in this Special Issue focus on Adriatic Sea sediments, both building on the PALICLAS findings. First, Luigi Vigliotti *et al*. present palaeomagnetic and rock magnetic data from five Adriatic cores. They combine ^{14}C dating and the age of magnetic inclination features to generate a robust age model and use the model to calculate changes in sediment flux from the Adriatic catchment and its routing within the Adriatic basin. Selective dissolution of magnetic grains allows the formation of sapropel S1 during the first half of the Holocene to be identified, and a major increase in sediment accumulation rate during recent centuries indicates progressive human impact in the Adriatic catchment and the rapid construction of the modern Po delta.

The second paper by Andrea Piva *et al.* is concerned with the use of planktonic and benthic foraminifera assemblages from a set of sediment cores collected on the Adriatic shelf and the Southern Adriatic deep basin to reconstruct sub-millennial scale environmental changes during the last 6000 years. The authors argue that the repeated peaks in *Globigerinoides sacculifer* represent warm-dry intervals, including the 'Mediaeval Warm Period', the Roman Age, the late Bronze Age and the Copper Age and that the last occurrence of *G. sacculifer* (550 yr BP) approximates to the beginning of the 'Little Ice Age' (LIA). The increased sediment flux during the LIA is well recorded by the shelf core and can be traced over several hundred kilometres within the clay-belt environment. Overall the climatic oscillations recorded by planktonic and benthic foraminifers in the Adriatic are consistent with those recognized in other areas within and outside the Mediterranean, suggesting a hemispheric-scale atmospheric connection. Human impact on the continent induces short-term fluctuations of sediment flux in the sites on the shelf (cf. Oldfield *et al*., 2003a), whereas deeper-water settings record exclusively climate-driven changes. Comparisons among the oxygen stable isotope records from the cores also allow identification of two major oceanographic turnovers in the Mid Adriatic Deep, the first around 7500 yr BP when the onset of the modern routing of the North Adriatic Dense Water is recorded by the shift of benthic foraminifer *B. marginata* δ^{18}O towards higher values, and the second after about 5500 yr BP when the northward intrusion of the salty Levantine Intermediate Water (LIW) is recorded by a major shift towards higher values in the δ^{18}O of intermediate-water dweller *G. bulloides,* pointing to an interval of increased evaporation in the Eastern Mediterranean where the LIW forms.

Ever since coming under the influence of Gordon Manley in Lancaster Frank Oldfield has been interested in high-resolution climate-change reconstruction. However, his attempts in the NERC-funded TIGGER project (Barber *et al*., 1999) in the mid-1990s to match lake sediment records to Manley's (1974) Central England Temperature series from 1659 to the present was thwarted mainly by the difficulty of accurately dating non-varved sediments. Mark Besonen *et al*. in their paper attempt to avoid the dating problem by focusing on varved sediments. From a record from Lower Murray Lake in northern Ellesmere Island, Canada that extends back over 1000 years they use back-scattered electron image analysis to provide varve thickness and other sedimentary indices of climate change on an annual basis. Although a relatively robust chronology is generated, perfect accuracy is precluded by problems of varve preservation and turbidite deposition. Allowing for these uncertainties the authors argue that the varve thickness record shows that summer temperatures in recent decades were among the warmest of the last millennium, comparable with conditions that last occurred in the early twelfth and late thirteenth centuries. The coldest conditions of the 'Little Ice Age' were experienced from ~AD 1700 to the mid-nineteenth century, when extensive ice cover on the lake led to widespread anoxic conditions in the deepest parts of the lake basin. Evidence for more recent warming is equivocal, with different interpretations possible depending on the parameter examined, demanding an improved contemporary understanding of the relationships between varve formation, climate proxies, climate and catchment processes.

The occurrence of 'abrupt' climatic events in the Holocene is a topic of great concern in global-change research (Oldfield, 2005). John Matthews and Quentin Dressser use detailed stratigraphical investigations of stream-bank mires in the central Jotunheim mountains of southern Norway to reconstruct the Holocene history of three glaciers. They show three broad phases of Holocene glacial changes (deglaciation, mid Holocene with few or no glaciers, late Holocene with enlarged and fluctuating glaciers). Superimposed on these broad phases, there are seven millennial-scale glacial events with glaciers larger than today. Comparison with data elsewhere in Norway and from the European Alps suggests 13 consistent European glacial events in the Holocene. These are poorly correlated with changes in solar irradiance. Matthews and Dresser suggest that forcing factors such as volcanic aerosols and, in the early Holocene, freshwater discharge into the North Atlantic may be important. The three broad phases appear to be a response to long-term changes in Earth's orbit. This study reinforces Frank Oldfield's (2005; Oldfield *et al*., 2003b) vision that Holocene climate changes result from a range of forcing factors operating at different spatial and temporal scales, interacting with local site factors and critical thresholds.

Concluding comments

On behalf of all his students and colleagues we pay tribute to Frank Oldfield's very many, varied and outstanding career achievements, and thank him for his generous personal help and support over our own careers. We wish him good health for the future and look forward to his continuing contributions to environmental change research for many years to come.

Acknowledgements

We would like to thank Dave Morley (London) for helping to compile Frank's bibliography and David Hunt (London) and Cathy Jenks (Bergen) for their help. We are grateful to Donald Walker for helpful comments on the manuscript. We also thank the very many international reviewers of the papers in this special issue whose willingness and, indeed, enthusiasm to serve reflects the exceptional regard in which Frank is held worldwide.

Appendix

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